# THE AMS-01 TIME OF FLIGHT SYSTEM

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The Time-of-Flight (TOF) system of the AMS detector gives the fast trigger to the read out electronics and measures velocity, direction and charge of the crossing particles. The first version of the detector (called AMS-01) has flown in 1998 aboard of the shuttle Discovery for a 10 days test mission, and collected about $10^8$ events. The new version (called AMS-02) will be installed on the International Space Station on March 2004 and will operate for at least three years, collecting roughly $10^{10}$ Cosmic Rays (CR) particles. The TOF system of AMS-01 successfully operated during the test mission, obtaining a trigger efficiency better than 99.9% and a time resolution of 120 ps for protons and better for other CR ions. In addition, the TOF system was able to separate protons from all the other CR nuclei within 1% and to distinguish between downward and upward crossing particles within at most $10^{-8}$.

## 1 Introduction

The *Alpha Magnetic Spectrometer* (AMS) [1] is a particle detector that will be installed on the International Space Station in 2004 to measure cosmic ray fluxes for at least three years.

During the precursor flight aboard of the shuttle Discovery (NASA STS-91 mission, 2–12 June 1998), AMS collected data for about 180 hours. [2] Figure 1 shows the detector (called AMS-1 in the following), consisting of a permanent Nd-Fe-B magnet, six silicon tracker planes, an anticoincidence scintillator counter system, the time of flight (TOF) system consisting in four layers of scintillator counters and a threshold aerogel Čerenkov detector.

The TOF system [3] was completely designed and built at the INFN Laboratories in Bologna. Its main goals are to provide the fast trigger to AMS readout electronics, and to measure the particle velocity ($\beta$), direction, position and charge. In addition, it had to operate in space with severe limits for weight and power consuption.

Each TOF plane consists of 14 scintillator counters 1 cm thick covering a roughly circular area of $1.6\,\mathrm{m}^2$. The scintillation light is guided to 3 Hamamatsu R5900 photomultipliers per side, whose signals are summed to have a good redundancy and light collection efficiency. The total power consumption of the system

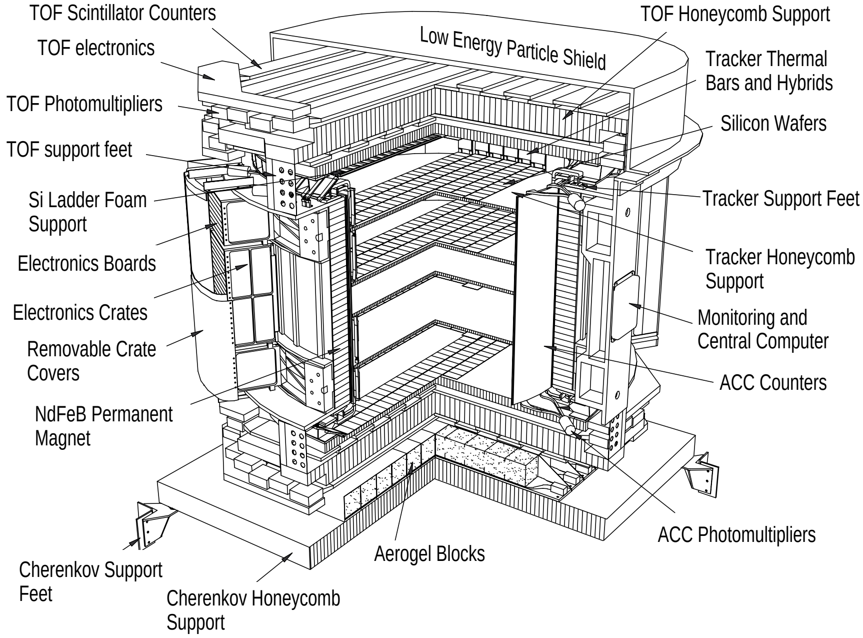


Figure 1. The AMS detector for the STS-91 mission (AMS-1).

(112 channels, 336 phototubes) was 150 W, while its weight (support structure included) was 250 kg.

## 2 The AMS-1 trigger

The AMS-1 trigger logic consists of three levels. The *fast trigger* (FT) processes the analog scintillators data and provides, in about 50 ns, the zero time for the time-of-flight measurement. The *first level trigger* rejects events with hits on the anticoincidence counter system and enhances the fraction of particles crossing the tracker planes through the analysis of the pattern of hit counters in the first and fourth TOF plane. Finally, at the last level the trigger logics suppress spurious fast triggers and finds preliminary tracks on the silicon tracker by using the digitized data.

The FT signal is generated when at least one counter side in each TOF plane produces a signal above a threshold corresponding to 40% of a minimum ionizing particle. The efficiency of this selection criterion could be measured with the same

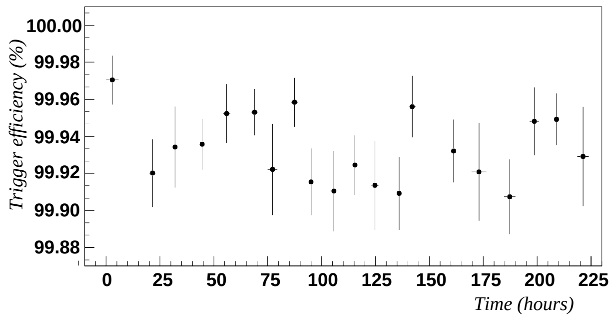


Figure 2. Fast trigger efficiency during the STS-91 shuttle flight.

data taken during the STS-91 mission, exploiting the characteristics of the TOF electronics, sensitive to all particles impinging on the detector in an interval of about 16 $\mu$s around the trigger signal. Up to eight hits can be registered by each channel with a time resolution of 1 ns and a full charge measurement.

The analysis of these unbiased data provided the instantaneous rate of particles, the dead time and accidental rate, in addition to the total FT efficiency. Figure 2 shows that this efficiency, for the whole duration of the STS-91 flight (data taken in the South Atlantic Anomaly are excluded), was always above 99.9%.

The background can be estimated by checking the consistency of the TOF data and the trigger mask, and comes out to be about 0.5% of the fast triggers (due to electronics noise). This background is completely eliminated in the last level trigger by requiring the coincidence of both sides of the same counter.

## 3 Time of flight resolution

The single channel time resolution is: [3]

$$\sigma(x) = \sqrt{\frac{\sigma_1^2}{N} + \frac{\sigma_2^2 x^2}{N} + \sigma_3^2}\,, \tag{1}$$

where $x$ is the distance of the particle crossing point from the photomultiplier (PM), $N$ is the number of photons which convert on the PM window, $\sigma_1$ depends upon the PM signal shape and the trigger electronics, $\sigma_2$ takes into account the dispersion in the photons path lengths and the constant term $\sigma_3$ depends on the electronic noise at the low threshold discriminator input and on the reference time dispersion on each channel.

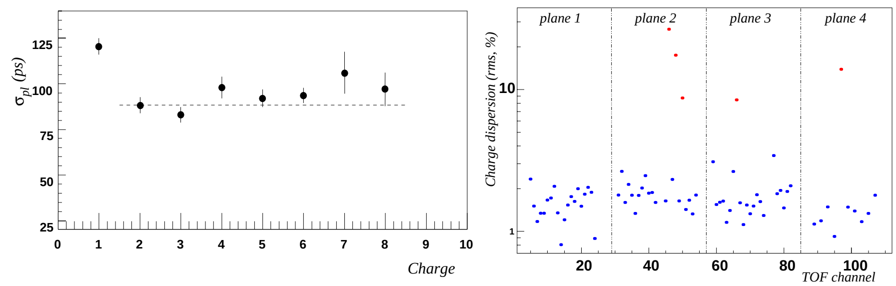


Figure 3. *Left*: single plane time resolution from the time of flight between the first and the second ($\sigma_{12}$) or the third ($\sigma_{13}$) TOF plane, and the mean time resolution. *Right*: TOF charge peaks dispersion during the STS-91 flight.

The overall time resolution of a plane can be determined by measuring the time of flight of ultrarelativistic particles between two given planes, after correcting for the track length.

The time dispersion is expected to decrease with the nuclear charge $Z$, due to the large number of photo-electrons produced by nuclei with high atomic number, until it reaches the minimum value $\sigma_3$. Figure 3 (left panel) shows the single plane time resolution as function of the particle charge: the horizontal lines show that the limiting level $\sigma_3$ is 88 ps.

## 4 Photomultipliers stability

The TOF system provides a measurement of the absolute charge of the crossing particle in addition to the tracker, even if, due to the strong constraints about power consuption, the TOF front-end electronics was not optimized for energy deposition measurements.

The charge measurement was realized through a "time-over-threshold" method, whose response is proportional to the logarithm of the deposited charge. This method results in a good separating power ($\approx 5 \times 10^{-3}$) between singly and doubly charged particles but has a poor charge resolution for $|Z| > 2$.

The stability of the charge measurement was very good for all the 112 TOF channels, but five channels, as shown in figure 3, right panel.

## 5 Particle separation

At the trigger level, one goal of the TOF system was to provide a special flag for ions. Accordingly, it was designed to distinguish in a fast and efficient way cosmic ray protons from other nuclei.

One of the main purpose of the TOF system is the measurement of the time of flight of the particles traversing the detector with a resolution sufficient to distinguish upward from downward going particles: an "upward-going" Helium nucleus wrongly labelled "downward-going" would be interpreted as an "downward-going" anti-Helium nucleus.

The average time of flight of the particles which traverse AMS is of the order of 5 ns, while the time measurement has a resolution $\sigma_t \lesssim 120$ ps, independent from the rigidity. Thus the probability to mistake the particle direction is well below $10^{-11}$, the level needed for successful operation aboard the ISS, where AMS is expected to collect at least $10^{10}$ events.

In addition, the velocity resolution of the TOF system, $\sigma(\beta)/\beta \approx 3\%$, allows to discriminate $\mathrm{p/e^+}$ and $\mathrm{\overline{p}/e^-}$ up to a rigidity of 1.5 GV.

## References


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